THE MODERN WEATHER BUREAU.

By Prof. Cleveland Abbe, M.A.

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This broad title may imply that I am to give a comparative study of the various weather bureaus of the world; but I shall to-night only have time to give some account of the Signal Service at Washington. It will be very gratifying to me if anything I may say or do shall contribute toward the founding of a similar organisation for the prediction of wind and weather in the South African States.

The study of the weather and the efforts to predict its changes are matters of most ancient and universal custom. History shows that the world has passed through several stages of weather science in its progress from barbaric ignorance to our present beginnings of a rational scientific meteorology. At the present stage of this science we wholly disclaim any belief in the special influence of the stars, planets or moon. We do not believe that plants or animals can furnish indications of the future weather. We have given up endeavouring to discover recurring cycles of storms and weather. We attach no especial importance to electricity or sun spots as a means of prediction. The modern meteorologist defines *climatology* as the study of averages in their relation to animal and vegetable life; but restricts *meteorology* to the study of the motions and phenomena of the atmospheric air and its moisture; this is therefore a study of the dynamics of gases and vapours; it requires the solution of a series of complex problems in fluid motion and thermo-dynamics. The forces that govern the atmosphere are numerous; the principal ones that I have been accustomed to consider in my daily predictions are as follows: (1) the sun's heat; (2) the radiation from the earth, the air and the clouds; (3) the moisture in the air; (4) the evaporation from the land and water surfaces; (5) the differences of density of hot and cold, or of dry and moist air; (6) the horizontal flow of air on a spherical earth whose diurnal revolution causes the well-known deflection to the right in the Northern Hemisphere, but to the left in the Southern, whence the equatorial and the polar depressions; (7) the influence of continents and mountains and especially of plateaux in causing upward deflections and consequent cooling and cloud with rain; (8) the cooling of ascending expanding air up to the level of cloud formations, and the influence of condensing vapour on the subsequent history of the cloud; (9) the less important influence of the variations of gravity with altitude and with latitude; (10) the variations in insolation due to the diurnal and annual changes in the position of the sun with reference to the zenith; (11) the less important conduction of heat from below the surface of the ground;

but the very important convection of heat up to the surface of the lakes and oceans ; (12) the consumption of heat in the evaporation of water and snow.

The preceding may not be a complete list of the items to be considered, but suffices to show the complexity of the problems that confront the student of our atmosphere ; doubtless most weather predicters attempt to avoid the laborious working out of atmospheric laws by simply utilizing our general knowledge of atmospheric changes, especially since we have now had ten or twenty years of tudy of the weather maps and of the areas of high and low barometer ; but the foundations for a true deductive and philosophical treatment of these problems have already been laid. The motion of a storm centre is a more complex problem and presents more mathematical difficulties than the motion of the moon does to the astronomer, it is in fact only capable of being handled by a mixture of analytic and graphic methods, since no algebraic formula can represent the irregular resistances of the earth surface so simply as can be done by graphic methods, and the same may be said of our thermo-dynamic problems for which graphic methods have also been specially devised. The last decade has seen important additions to the ranks of those who are studying the atmospheric problems. I will stop only to mention the memoirs of Sir William Thomson on the stable flow of fluids, of Helmholtz on discontinuous movements in the atmosphere, of Oberbeck on the general currents and on the whirlwind movements ; memoirs by Hertz and Berold on the thermo-dynamics of the atmosphere ; by Poincaré on the atmospheric tides due to the moon ; and even from Japan comes an elaborate paper on atmospheric motions by Diro Kitao, President of the College of Agriculture in the University of Tokio, in which he has elaborated such views as I suppose must have been communicated by Helmholtz or Kirchoff, in their lectures to their students. But these most recent contributions must not make us forget the work done by the fathers of the new deductive meteorology, and as such we must hold in high esteem two American citizens, James P. Espy and Wm. Ferrel. Espy is frequently quoted as the author of the centripetal theory of storms as opposed to Redfield's circular theory, but the fact is that both of these students were fully aware that in nature the winds blow neither directly towards nor circularly around a storm centre. It was only in the heat of a personal discussion that each was led for a moment to characterise his idea of storm winds as centripetal and centrifugal respectively ; meaning thereby simply that this was the most prominent feature in his mind. Espy's special claim to our gratitude is his clear appreciation of the thermal processes going on in the clouds. He was always in search of the reasons why, and it was a great step forward

when about 1833 he announced the latent heat evolved in the condensation of vapour into cloud and rain is the sustaining power of the storm. We owe to Espy the practical introduction in 1830 of the whirled Psychrometer, a table for use with it for obtaining dew points, the determination of approximate rate of cooling of ascending air, the correct explanation of the diurnal period in the velocity of the wind and a series of daily weather maps for the United States based on an hundred stations for over 15 years (with occasional gaps) ; a selection from these maps is published in his reports, and the whole work led him to a long series of generalizations as to the movements of storms over the United States. In this latter work he was the pioneer of the world, and to the present day no one man has, so far as I know, accomplished any greater work in meteorology. I wish I could stop to tell you more about him, for he was personally one of the most interesting figures in the annals of science. His ancestors were Huguenots who had fled to Northern Ireland and thence emigrated to Lancaster County, Pennsylvania, where their descendants held distinguished positions in public and private life ; he was himself thoroughly educated in the languages and law ; he received his title "professor" from being at the head of well-known academies ; first in Cumberland, Maryland, afterwards in Philadelphia. Very early in life his attention was drawn to the study of storms, and from 1817 to 1857 he observed, studied, wrote, and lectured everywhere on this subject. Being so far in advance of his time it was natural that the community should seize upon and exaggerate some features of the views maintained by him ; but his soubriquet, "*The Storm King*," correctly pictures the impression he made upon all his hearers. His enthusiasm was intense and led him to talk, write, and lecture upon his views whenever occasion offered, hoping thereby the sooner to convince his fellow-citizens that storms and weather can be predicted.

In 1847 Prof. Joseph Henry, in his first report as Secretary of the Smithsonian Institution, publicly came to the support of Espy, with whom he had for ten years had frequent intercourse in Philadelphia and Princeton. In 1849 Henry obtained from the Electro-Magnetic Companies the privilege of receiving at Washington daily weather telegrams free of expense, the same to be used for the purpose of studying storms and of demonstrating to the members of Congress that the weather can be predicted from day to day. This gratuitous assistance was rendered by the telegraph companies all the more readily because it was well recognised that the electro-magnetic telegraph, as it then existed, would not have been possible but for the discoveries in electric science made just previously by Prof. Henry, in his laboratory in Princeton, and which had been utilized by Morse and his assistants. Henry's interests in meteorology now came to be

a prominent feature in his activity, and his lectures on the subject, which have been lately published by the Smithsonian show him to have been far in advance of most writers at that time. From 1851 to 1860 Prof. Henry maintained at Washington a daily weather map based on his morning telegrams, and he continuously used this chart as an argument for the establishment by Congress of a National Weather Service. His contract with the telegraph companies only allowed him to use his gratuitous telegrams for this and for scientific purposes, otherwise he would doubtless have made public the predictions which were frequently made at the Smithsonian for the use of Congress. You must recall that in America the telegraph belongs to a private business corporation, and the latter was not willing to transmit telegrams for the general public benefit unless in some way the public should pay for it. Prof. Henry's object was humanitarian, *i.e.*, to so familiarize Congress with the possibility and advantages of the system as to induce that body to establish and support a proper system for the public welfare. But our Congress generally follows rather than precedes the expressed will of the people and it delayed action until popular opinion should seem to demand it.

Henry's weather map was interrupted during our "War for the Union" and when in 1868 I took charge of the Astronomical Observatory in Cincinnati I resolved to revise the work in some such way as to make it useful both to the community at large and to science. I had already paid much attention to the study of atmospheric refractions, and in order to perfect our knowledge, I saw that we must not only understand the motions of the atmosphere but must surround the Observatory by a system of weather stations, and have the data for drawing daily maps showing the positions of the storms with reference to the astronomical observer. With the consent of the trustees of the Observatory, I presented my plans to the Chamber of Commerce in that city, many of whose members had long been accustomed to utilize weather telegrams in their daily business. The response of this important body of business men was immediate and favourable, so that on the 1st of September, 1869, I began publishing for the use of the Chamber of Commerce "The Weather Bulletin of the Cincinnati Observatory."

This bulletin gave full statistics of the condition of the atmosphere at numerous stations from the Rocky Mountains to the Atlantic States, and from the Gulf of Mexico to Canada ; its observations were at 8 a.m. Cincinnati time, and it was published at noon daily. At the bottom of the sheet was a prediction, which I called "Probabilities," for the next twenty-four hours. Although the nickname "Old Prob" subsequently followed me to Washington, yet by courtesy it has come to be now generally given to the Chief Signal Officer, *ex-officio*.

In the weekly bulletin of the French Association for the Advancement of Science, you will find a letter of mine written at this time to Leverrier offering him a daily synopsis of American weather for use in European predictions. A project that has since been realized, although of course we have not yet learned how to make the best use of American weather synopses in the predictions of European storms.

While my work in Cincinnati was in the first months of its infancy, it was everywhere well spoken of by an appreciative public press as a step in the right direction. My correspondent in Milwaukee, Prof. J.A. Lapham, not content with sending me his daily weather telegram, determined to, if possible, secure predictions for the benefit of the commerce of Lake Michigan. I had myself some months earlier presented the same subject to the Board of Trade in Chicago and also to the daily newspapers in New York, and the better success of Prof. Lapham's efforts was largely due to the counsel of his friend, Gen. H. E. Paine, the member of Congress from Milwaukee, who, as he himself has told me, advised that the memorial prepared by Lapham for use in the West, should instead be addressed directly to Congress; he also suggested that the "National Board of Trade," as representing all the business interests of the country, should be asked to support the project of a National Weather Bureau for the benefit of commerce and agriculture The next meeting of this Board occurred at Richmond, Virginia, in November 1869, and on that occasion the delegates from Cincinnati united in the support of the resolutions favouring a national system that were introduced by the delegates from Milwaukee. In December, Gen. Paine submitted to our Congress, at Washington, the memorial prepared by Prof. Lapham and a "Bill" that proposed the establishment of a National Weather Service to be conducted by a high scientific authority. Immediately that this step became public, the Secretary of War authorized the Chief Signal Officer of the Army to present his views on the subject of storm and weather signals, the outcome of which was the passage on February 4, 1870, of a "Joint Resolution," authorizing the Secretary of War "to organize a system of telegrams and reports for the benefit of commerce and agriculture." On this comprehensive base, the Secretary authorized Gen. Myer to build up a great meteorological system, which his successors, Generals Hazen and Greely, have developed and modified until at present it constitutes a near approach to the ideal Weather Bureau, and as such invites our attention to-night.

The original organization of the Signal Office is due to Gen. A. J. Myer, and it was conceived by him before 1860, but during our four years of war received its greatest development. Established as a separate corps of the army, the signalmen and officers were required

to be expert in all manner of signalling, in cypher writing and decyphering, and in building and manipulating all forms of telegraphs. It was a very perfect organization for gathering information from all parts of the country for the use of the Commander-in-Chief. And now Gen. Myer proposed in times of peace to devote its energies to this new work of charting and predicting the weather. Every officer was at once ordered to study meteorology. Circulars were issued inviting the co-operation of scientific institutions. I recall sending him the instructions, forms, cypher-code and other material used at Cincinnati. By the use of this cypher all needed data for any one station could be telegraphed in five or ten short words with small chance of any troublesome telegraphic error. New Signal Service observers were especially enlisted for the weather service, and devoted their whole time to the various kinds of work that it was soon found necessary for the service to engage in. The problem as it presented itself to Gen. Myer embraced at least three main features : (1) Observation and telegraphy for the formation of a weather chart at Washington, the chart to be finished within two or three hours after the observations were taken simultaneously throughout the country. (2) The preparation of prediction and ordering of storm signals. (3) The forcing of these predictions to the attention of every one interested as quickly as possible. This last, which might seem at first the most difficult, was easily arranged through the co-operation of the various Press Associations and railroad and telegraph companies. In addition to the weather the important river floods in the Ohio, Missouri and Mississippi were observed and predicted. In 1874 the scope of the Signal Service organization was greatly enlarged by the addition of the observers who had hitherto reported to the Smithsonian ; these are known as the voluntary observers. About the same time also we began to receive the monthly reports of the military observers that had hitherto reported to the Surgeon-General of the Army. By means of all this new data the monthly weather review, that I had started for Gen. Myer in January 1873, and that had hitherto dealt principally with the phenomena of storms, was enlarged so as to cover the general climatology of the States. My own connection with the office began in January 1870, and was as I then supposed only temporary ; in a short interview with Gen. Myer, he stated that having organized the observers and the telegraphy he now wished me to come to Washington and organize the system of probabilities and storm warnings. My first work was to chart the observations, draw in the isobars and write out the predictions for the day. These predictions began to be published by the office about the middle of February 1871 ; they owe their success largely to the fact that I was not required to predict for public use *every* feature of wind and weather and temperature, but only such

decided changes as I could foresee as highly probable ; subsequently the rule was established that every feature must be predicted, and it was under this arrangement that about 85 per cent. of verifications was considered as attained. In May 1871 I compiled for the service a little pamphlet entitled " How to use Weather Maps." This served to show that the predictions were in no sense empiric ; but were based on deductive processes of reasoning, that utilized the laws that had been established up to that time by such men as Espy, Ferrel and Wm. Thomson. A few months' experience gave me an opportunity to show Gen. Myer that the proper study of the storms on the coast required the charting of additional observations from vessels at sea. Accordingly during our first year he issued a circular asking that simultaneous observations be made on all vessels at 12·43 Greenwich time ; in September 1873 he secured from the Meteorological Congress at Vienna a vote to the effect that simultaneous observations throughout the whole Northern Hemisphere were desirable. This vote he construed as an endorsement of the requests independently made by him to every nation of the world asking for the interchange of simultaneous observations.

In 1874, such simultaneous observations began to be made by our American Navy, and now this widespread international request was very generally acceded to, so that in 1875 I had the pleasure of organizing and editing the first issues of the " *Bulletins of Simultaneous International Meteorological Observations made at 7.35 a.m. Washington time.*" To this was subsequently added the corresponding daily chart for the Northern Hemisphere. Such a chart as this constitutes the true and only sufficient basis for the study of the movements of the atmosphere. The only serious defect of the S.S. charts of the Northern Hemisphere resulted from the fact that very few systems of observation except that of the United States pay sufficient attention to the appearances and movements of the clouds, although every one recognises the fact that the clouds have a controlling influence in all our phenomena. Both lower and upper clouds were observed with the greatest pains by myself at Cincinnati and by many of my observers ; such observations began to be telegraphed to Washington and inserted on the manuscript tri-daily Signal Service Charts toward the close of 1871, when a cipher code similar to that used at Cincinnati was adopted by the Signal Office. It must be apparent to any one that the study of the clouds down to the very horizon gives one a comprehensive knowledge of the atmospheric conditions an hundred miles away. We often speak of the temperature and the wind as being very local phenomena but of the barometric pressure as a more general phenomenon. What shall we say, then, of the clouds which, as carefully observed by one man, will enable him to say whether the air currents

are ascending, descending or horizontal, or whether the distant clouds are moving parallel to those near by, or whether all are moving in curved lines around distant areas of high or low pressure? I am at present engaged in a close study of cloud movements on the Atlantic Ocean, and can safely state that without a single exception the clouds have revealed to me the presence of distant storms and the proper steering course to avoid them, and the same may be said of the minor changes in the direction of the wind. Your "*Table Mountain*" has afforded me many beautiful illustrations of motions in the atmosphere, such as I knew must take place, but had never before seen exemplified; your mountains in the interior, with their accompanying great cumulus clouds and their overflowing cirrus-tops, have given invaluable data as to the general circulation of air on the coast of Africa. I cannot too earnestly urge upon you the observation of the growth and decay and movements of the clouds.

But to return to the Signal Service. The most important step of progress taken by General Myer's successor, General Hazen, was I think the recognition of the fact that by introducing civilian scientists into the organization there would come a more rapid assimilation of the nerves and best thoughts current in scientific periodicals. He therefore engaged the services of Ferrel, who had long been employed in our "*Coast and Geodetic Survey*" and of Mendenhall, who is now the Superintendent of that survey. Among the younger men he secured Messrs. Upton, Hazen, Waldo, Curtis, Marvin, and Russell, all of whom have reflected credit on the service. To General Hazen we owe the carrying out of a plan that for many years had been near my own heart, namely, the organization of State weather services for the study of local details. Such independent services were not in accord with General Myer's policy, but their advantages were seen by General Hazen. After the preliminary steps were taken this branch of the service was entrusted to the senior military assistant Lieutenant Dunwoody, with whom some thirty local State Weather Services are now in correspondence; those have been the means of stimulating the study of meteorology and of rendering the Signal Service better appreciated. In 1881, when the work of the International Polar Commission needed a little stimulus, Gen. Hazen announced that the Signal Service could maintain two Arctic stations—an announcement that we had reason to think decided the wavering European Governments. One of these stations was that for which General Greely had been making preparations, whose work and energy have justly claimed the admiration of all. On the death of General Hazen the President appointed General Greely as his successor. He had long been familiar with every form of Signal Service work, and the volumes published by him fully attest his ability to do an enormous amount of work under most trying

circumstances. Under his hands the Signal Service is entering upon a new career; it has become even more decidedly a mixed military and civil organization, thereby responding to the evident desire of the people and of Congress. He has also succeeded in accomplishing a considerable reduction in the annual expenses of the office. Counting upon our long experience in the study of weather maps made up three times a day, namely, for 7 a.m., 3 p.m., and 11 p.m., he has made the experiment of diminishing the number of reports and maps, and our predictions are now based on two complete maps per day, namely, for 8 a.m. and 3 p.m.

But the history of the Signal Service will perhaps not interest you so much as an account of the preparation of the weather maps and predictions. I have exhibited upon the wall a series of the large 7 a.m. weather maps as published every day at 11 a.m., and which maps can be consulted here at any time in the archives of your Meteorological Commission. A series of such maps is a rarity even in the United States, and I hope the duplicate copies received by your Commission will stimulate some one in Cape Town to study American weather, at least as faithfully as Americans would be glad to study Cape Town weather. Our observers have their stations located in the large cities near the telegraph offices, and frequently on the tops of our highest buildings, so that some of them are from 100 to 150 feet above the ground. The morning observations that you see on these charts were made simultaneously at Greenwich noon, which corresponds to 7 a.m. by the clocks used throughout our Atlantic States, and to 4·00 a.m. by the clocks used throughout the Pacific States, for you must know that in October, 1884, our innumerable railroads lifted from us the great burden and bugbear of "MEAN LOCAL TIME," and gave to each section of the country a simple system of Standard Meridians at the successive whole hours of longitude west of Greenwich, to the great advantage of the public and the railroads. This is also a great boon to terrestial physics, since now whenever any one reports to us an observation of a meteor, an earthquake, an aurora, or a tornado, we easily find what standard time he used and the probable relation of his own to other observations. It was the hopeless impossibility of properly co-ordinating the observations of our voluntary observers that led me, while studying the aurora of 1874, to propose this simple system and subsequently to write the report published in the "Transactions of the American Meteorological Society" which report in the hands of the general superintendent of our railroad time service (Mr. H. A. Allen) enabled him to hopefully and successfully renew his efforts to bring about this great reform in our domestic clocks. At present the mean time of the 75th Meridian is that used in all Signal Service work and is the official standard of the Government at

Washington. In old Anglo-American law, however, the apparent noon and sunrise and sunset are still legal.

The simultaneous observations that are in the hands of our observers throughout the country by 10 min. after 7·00 are corrected, reduced and enciphered (five cipher words generally convey the whole message), and are personally carried to the adjacent telegraph office, unless, as most frequently happens, there is a special telegraph line between the two offices. The lines of wire passing through successive distant stations towards the central station at Washington are for a few minutes entirely at the disposal of the Signal office, and lead into a special room in our building, where some half-dozen operators are seated ; in a few minutes (rarely more than five) all the messages have been received from stations along any one line of wire, and in from twenty to thirty minutes all may be received from the whole country, including those from Canada. The total number of stations thus heard from is usually about 150 ; they spread over a region of 1,800 miles north and south, by 3,000 east and west. Copies of these despatches go simultaneously to other cities where maps and predictions are also made, but we will confine our attention to Washington. Adjoining our telegraph room is the room for charting and predicting ; here one may see at a central desk the so-called "translator" to whom telegrams are brought as soon as received. He, having our cipher code committed to memory, immediately reads aloud Metcorological items. Around the room are desks for the clerks who do the charting and for a type-setter, as also for a clerk who compiles a tabular bulletin of reports ; all listen to the translator and immediately write or chart such of the items as they individually need. Thus one charts the barometric departures and their changes ; another the temperature departures and changes ; another the clouds and their motion, the dew point and the maximum or minimum temperature ; but the principal map is considered to be that which shows the wind and weather. rainfall, temperature and reduced barometer. On this latter map the "predicting officer" or "Young Prob" draws the isobars and isotherms, then makes a tracing of them and sends that to the lithographic printer who is in the printing-room on the ground floor immediately beneath. Simultaneously the type-setter sends to the lithographer a copy in transfer ink off the columns of figures you may see in the lower right-hand portions of these morning maps. And at the same time the clerk sends a copy of the bulletin of full reports. Now the predicter without much hesitation dictates the synopsis and probabilities that you see printed in the lower left-hand portion of these maps. His dictation is not written down but is set up in type by the type-setter as fast as he cares to talk. And a print of this is made in transfer ink and sent down to the printing room.

In this latter room the lithographer has already prepared a supply of the blank base map. He has also a solid metallic form, of the size of this map, in which are cut slots for the insertion of square type or dies. He puts in each slot the type that represents the wind and weather as you see them here printed, and prints one copy of these symbols in "transfer ink." He then transfers this "symbol-print" to a large lithographic stone and also transfers to the same stone the isobars the isotherms, and the left and the right hand corner tables. All this work is being carried on simultaneously by several and he is ready to print the special morning map all that you see here in red on the green base map, in about 20 minutes after he receives the data from the prediction room. The schedule of time was formerly about as follows for these 7 a.m. maps: observation at 7 a.m., telegraphy 8 to 8.30, prediction finished at 9.30, map printing begun at 10 a.m.

For the 8 a.m. observation now employed the time is shortened and the printing begins about 9.30. You will understand that this same routine is again gone through from 4 to 7 p.m., and again from 10 p.m. to 1 a.m., and it has so gone on without a single intermission for holidays or Sundays, or a single failure since January 1871, so far as maps and predictions are concerned, and since June 1871 so far as printed maps are concerned.

In answer to a question from Dr. Gill I would say that the clerks rotate in their duties, but that the same predicter must be on hand for at least a month, when he may be relieved by another. It has been found quite impracticable to have different men do the morning and night predictions, one person must take the entire responsibility for the time being. He lives as it were in continuous contemplation of the weather; he comes to the study of each new weather map with a vivid remembrance of the conditions shown on the preceding map; the eight or twelve hour intervals do not allow him to forget anything, as might be the case with twenty-four hour intervals. He comes to the new maps expecting to find certain changes, and if any of these have not occurred then these are the features that demand especial attention and study. The Signal predicting officers were formerly never known to the public by name, but of late years their names have been published in the Monthly Weather Review in connection with a statement of the percentages of verification. I take pleasure in adding that Captain Robert Craig and Captain H. H. Dunwoody, who in 1872 began to alternate with me as predicters, are still engaged in the Signal Office, in that or cognate work. Captain Dunwoody is regarded as our best predicter at present.

But the printing of our weather maps is merely the official record of our work and does not suffice to make our predictions practically useful to the people; it is this latter result that is a most vital feature in the

organization of the office. Long before the maps can reach the people our predictions have been sent by telegraph to every part of the Union; they have been printed by enterprising newspapers, they have been bulletined at public places, such as telegraph and railroad offices and Chambers of Commerce; by means of signals, usually flags, the approach of storms, rain, blizzards, local and northern, have been announced; finally, the early morning railroad trains have displayed on the sides of the luggage vans signals embodying the midnight predictions, so that any farmer watching the train as it flies by in the gray dawn is put in possession of as much knowledge of the coming weather changes as we can send him from Washington.

All this organized effort to observe, concentrate, predict, and disseminate useful information about the weather employs the whole time of some 500 or 600 Government employés, and enlists the voluntary co-operation of thousands more. The expense or rather the outlay on the part of the people is not merely the one or two hundred thousand pounds sterling that is appropriated by Congress, but the vastly larger sum total of all that is done by the many friends of the service, and we think there is no shadow of doubt but that every fair-minded citizen concedes that it pays him to heed the weather predictions. We have, of course, many cases where spasmodic attention to them disappoints the farmer, the shipper, the railroad superintendent, the sea captain or others; but opposed to these few is an innumerable majority who uphold our work and testify in the most convincing figures that health, property, and business enterprises prosper in proportion as they study, understand and heed the predictions. It is perfectly plausible that this should be their conclusion, for I calculate that without our reports, one can in the United States predict the weather for the coming day for his own locality correctly about 65 times out of 100, but with the predictions certainly 85 times; we have therefore helped him 20 per cent. towards a perfect fore-knowledge, and on the average of the year he should be 20 per cent. better off in all his affairs. Such a gain fully justifies the expense of the signal service, and in general this percentage represents the ratio by which science enables civilised races to annually forge ahead of those nations that neglect the advantages that knowledge offers to mankind. It does not pay to be left behind in the race of progress.

I cannot close without showing you these daily maps of the weather in South Africa.

I was about to prepare some such maps in order to illustrate to you the weather and clouds that I have been observing here during the last week, and was wishing for maps to illustrate your winter weather, when to my delight I made the acquaintance of one of the most persistent students of meteorology that is anywhere to be found, your

fellow-citizen, Mr. A. G. Howard. It has been a high privilege to me to enjoy the study of the instructive series of maps compiled by Mr. Howard for the five years past. I show you now the volumes that he has kindly lent me, and can assure you I hope to have these published in America as an important contribution to meteorology, and one by which we in the northern hemisphere may profit almost as much as yourselves. Mr. Howard has rightly appreciated the recent advances in meteorology, and in this special series of twenty large maps he has located the position of the oval or wedge shaped area of low pressure towards which blew the heavy winds that formed your severe storm of July 22nd, 1889. On this final chart I have drawn what seems to me likely to have been the course of the centre of this low area. Mr. Howard has prudently avoided locating any such hypothetical centre, but I myself should not hesitate to say that the winds can be properly described as coursing toward and around a long oval depression. We have in the States observed many such long ovals, sometimes like troughs, but which eventually close up to nearly circular storm centres.

I may here caution you against a very common error, namely, that low barometer makes the wind. The fact is just the reverse and the true process is as follows : When air becomes buoyant and rises, there may be a slight barometric depression, but this is usually so slight as to be entirely unmeasurable. Air is so mobile that an imperceptible linear gradient sets it in motion, but once in motion the rotation of the earth causes it to deflect a little, and immediately there is set up a vortex motion ; now in all such vortex motions centrifugal force causes the flowing air to press outward and there is a corresponding diminution of elastic air pressure as we go towards the centre—in a storm of small dimensions it is the rate of this diminution that the barometer measures and that we call the gradient while in larger storms the rotation of the earth introduces a further cause for the fall of the barometer—such for instance as we see in the equatorial belt of low pressure and in the arctic and antarctic areas of low barometer. Thus in general the observed low pressures and the high pressure are the *results* of the movements of the air, while those movements are themselves the results of barometric gradients that are almost inappreciable and have never yet been observed by meteorologists.

A single experiment will illustrate my meaning. Let the water in a basin become very still and then carefully open a small hole at the centre. So long as the water flows in straight lines towards, down and out of the aperture, you will see no appreciable dimple at the centre of its upper surface, but so soon as the slightest whirling begins, the dimple appears and very soon becomes a funnel-shaped hole down to the bottom. This funnel is directly due to

the rotation of the water, not to its flow through the hole. Just so, a storm whirl occurs beneath a cloudy region where the buoyant clouds are ascending, and the colder air is flowing inwards, around and upwards. Within such a whirl the barometer measures the local pressure of the elastic gas and not simply the weight of the air above it.

The rectilinear and the vortex motions, or the direct, the sinuous and the spiral motions of fluids, offer most important but difficult problems to the meteorologist and mathematician. When the air is moving very slowly it can easily keep on in straight lines or very gentle curves, but so mobile is it that when moving rapidly, nothing can prevent its twisting into innumerable vortices, as shewn in the clouds and the dustwhirls.

But I was speaking of Mr. Howard, and his storm of last July. I find that the flow of *dry* air from the continent into this storm area has deflected the whirl away from the dry area just as it does everywhere in the northern hemisphere. Thus on the east coasts of North America and of Asia the whirls are pushed from the dry land towards the south and east; on the west coast of Europe they are pushed from the dry land towards the north and west, that is to say, these are the deflections from the normal or average. It is equally proper to say that the storm centre advances or grows towards the region where the maximum rain and snow occurs, *i.e.*, towards the supply of rising moist air. Apparently the north-west wind along your west coast was overlaid last July by a dry north-east, and the latter had little moisture wherewith to feed this whirl of last July, so it deflects to the south, passed east of Agulhas, and then moved north-eastward.

But you need stations further north, and possibly I have not fully appreciated all the forces at work in this storm, so that Mr. Howard may yet prove to have the more correct view. All that I would insist on to-night is, that storms and weather can be satisfactorily predicted twenty-four hours in advance by the proper use of the telegraph, that such predictions or even vaguer ones are far better than to have none at all, and that through Mr. Howard's knowledge you can in South Africa have as good a weather service as you are willing to pay for.

CLEVELAND ABBE.